TEACHING ENGINEERING HABITS OF MIND: AN EMPLOYABILITY STRATEGY THAT INVOLVES CHANGING EDUCATORS' HABITS OF MIND

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An education system that cultivates a sufficient number of employable engineers seems to be hard to achieve. However, it has been demonstrated that education that focuses on developing habits of mind, such as perseverance and curiosity, has great potential for enhancing an individual's success in the labour market in the longer term. Therefore it is important to understand how best to incorporate these dispositions, often unhelpfully called 'softer' skills, into the STEM curriculum. Having identified six Engineering Habits of Mind (EHoM) for Royal Academy of Engineering in earlier research, in this paper we explore the pedagogies underpinning the cultivation of these EHoM in the classroom. We outline initial findings from a project where we have been collaborating with teachers in primary, secondary and further education contexts using an action research methodology to support them in embedding the teaching of EHoM into science, mathematics, design & technology and engineering curricula. This paper explores four specific pedagogic strategies that have emerged to cultivate EHoM and discusses ways in which their use might have an impact on the role of educators.

Keywords: engineering habits of mind, engineering education, pedagogy, employability

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1. INTRODUCTION

1.1 Challenges for educating employable engineers

An education system that inspires young people to become engineers and produce a sufficient number of employable graduate engineers or engineering technicians seems to be hard to achieve (IET 2015a). Furthermore, the profession is also concerned by reports from employers that they find young people leaving education are lacking in key employability skills and attitudes (IET, 2015b). Positive pedagogic changes have been taking place in engineering education but it seems to take a lot to convince academics of the need to change their teaching approaches to encompass employability skills. A lack of specificity about the naming of these important skills and dispositions, with terms used including soft skills, employability skills, twenty-first century skills, social skills, non-cognitive skills and most recently 'character' skills, causes much confusion that detracts from the task of finding ways of developing and improving them (Claxton et al., 2016).

1.2 Importance of developing 'soft' skills for employability

There are now compelling reasons as to why it is important to change the teaching of science, technology, engineering and mathematics (STEM) subjects in order to develop employability skills more visibly. It has been demonstrated that education that focuses on developing 'soft skills', or dispositions such as perseverance, sociability and curiosity, has the potential for

enhancing an individual's success in the labour market in the longer term (Heckman & Kautz, 2012).

1.3 Could engineering habits of mind foster employability?
It is important to acknowledge that pedagogies for engineering and other STEM subjects have been changing to meet the needs of students and employers. Interactive pedagogies such as problem-based and project based learning to support problem solving are more common; group work and peer learning develop collaborative team skills; work-based placements, internships or extra-curricular activities foster work-place awareness; and entrepreneurship courses foster creativity. However, it is clear that there is still more to be done to ensure that young people who might aspire to engineering as a career have the necessary skills and dispositions to achieve this goal. In many cases, although the pedagogy has changed, the skills themselves are being developed in spite of the intervention rather than as a result of it. Many teachers are still not familiar enough with the skills themselves to teach them effectively or do not see it as their responsibility to do so (Hermon & McCartan, 2010). However, if appropriate pedagogies were more visible, more teachers may be willing to change their practice.

Habits of mind (HoM) is an expression used to describe aspects of intelligence. The term was adopted by educationalists Costa and Kallick (2002) who identified sixteen HoM which, taken together, describe what *"smart people do as they go about their lives successfully dealing with whatever unexpected problems are thrown at them"*. They also suggested that the role of teachers might change if they were deliberately trying to encourage the development of HoM in learners. We drew on this body of work and our own research into learning dispositions to identify six engineering habits of mind (EHoM) that refer to the specific ways of thinking and acting as an engineer. These include "systems-thinking", "adapting", "problem-finding", "creative problem-solving", "visualising", and "improving" (Lucas et al., 2014). This paper reports on our project to identify pedagogies that cultivate engineering habits of mind and to make these more visible to STEM teachers, with the aim of enhancing students' academic achievement in STEM disciplines, and in parallel, cultivating dispositions that make them more employable.

2. PROJECT METHODOLOGY

2.1 Research aims, recruitment and project activity
Our premise is that if young people are taught to think like an engineer, more of them might aspire to continue into an engineering career, so we aimed to expand teachers' understanding of EHoM and help them acquire and use pedagogies designed to cultivate EHoM in the classroom. We purposively recruited primary teachers as well as secondary and FE teachers from 11 participating schools and colleges who were willing to engage in a continuing professional development (CPD) activity in which the teachers undertook small scale, classroom based teacher inquiries. In year 1 (2014-15) the teachers were supported to embed EHoM in their STEM subjects through three professional development activities. They were familiarised with EHoM and the principles of action research in a CPD workshop led by the project team, they were supported as they undertook their classroom-based activities to embed EHoM within their teaching, and they joined the Expansive Education Network, a large professional community of like-minded teachers. In year 2 (2015-16), again with support from the team, they continued with a further round of teaching interventions. At the end of the first year the teachers wrote brief reports and presented their findings to their peers

at a dissemination conference in July 2015. These reports have provided the pedagogic examples given in this paper. Further data from year 2 will be gathered through interviews with the teachers in May and June 2016 which will be analysed and reported at the ISEE 2016 conference.

3. HABITS AND THEIR FORMATION

3.1 What are habits and how are they formed?

In order to deliberately cultivate or change habits it is important to be clear about what they are and how they are formed. In this section we explore the common characteristics of habits and the processes of habit formation in order to enhance understanding of how learning and teaching environments may be arranged to support the development of effective habitual learning behaviours, for example, EHoM. Habits are essentially neutral of themselves, but depending on when and where they are deployed by an individual, they may help or hinder the demonstration of effective and socially acceptable behaviours; for example, perseverance, good timekeeping and relating to others in a friendly manner normally help individuals to progress in the classroom and the work-place, whereas being addicted to taking drugs or being unreliable do not. Habitual behaviour is useful because it enables people to study or work efficiently in familiar environments and it also provides individuals with a ready response when they might be distracted from deciding on an action or tailoring a response to a task through tiredness, time pressure or stress. Again, these habitual actions may, of course, either help or hinder the individual (Wood and Runger, 2016).

Habits therefore have three core defining features; they are automatic responses, they are generated in response to a trigger or cue, such as an event, action or person and they are undertaken in pursuit of a goal that brings a reward (Lally and Gardner, 2013; Wood & Runger, 2016). However, habit formation is a slow, incremental process and habitual behaviour is very resistant to change. Lally and her colleagues found that it took up to three months of daily repetition for a healthy practice, such a eating a piece of fruit after a meal, to become habitual, even when there was motivation and commitment to change to more healthy eating habits (Lally et al. 2010). There are three key factors that are thought to encourage the development of habits; constant repetition of the habitual action, a stable context in which to perform it, and the provision of an appropriate reward for completing the action (Lally and Gardner 2013; Wood and Runger, 2016).

However, even if habits appear to be entrenched, they can change when the contexts that trigger the cues change. This is particularly likely to occur at transition points in an individual's life, for example, when a child moves to a new school or a student moves from college into a job. In the absence of familiar cues, this transition may offer an opportunity to generate new habits or reduce the chance of former habits being transferred to the new context, but again, depending on the habit, this may result in positive or negative outcomes for the individual (Wood et al. 2005). It is important therefore that education and employers work closely together to facilitate the transfer of young people from education in to work.

3.2 What does all this mean for learning and teaching?

The three elements necessary for habit formation: repetition, context and reward, together with the need to consider the importance of transfer of learning to new contexts, provide us with four clear pedagogic principles around which to develop effective learning and employability habits:

- Teachers and learners need to fully understand the habit and recognise it when it is being used successfully;
- Teachers need to create the climate for the habit to flourish, including rewarding it;
- Teachers need to build the learning context and choose teaching methods which facilitate the practice and transfer of the habit;
- Teachers need to build learner engagement and commitment to the habit.

In the next section we illustrate how our four principles for cultivating effective habits can be used to develop EHoM. Some anonymised examples are taken from the data retrieved from our teachers' reports.

4. PEDAGOGIES THAT FOSTER THE FORMATION OF HABITS OF MIND

4.1 Pedagogies for cultivating habits of mind

Teachers in all sectors have been encouraged to adapt their teaching to enhance learners' skills and capabilities. We have noted the bewildering range of terms used to denote such skills in section 1.1. It appears however, that the 'softer' the skill, the more difficult teachers perceive the task of teaching it to be, or are more sceptical about the feasibility of teaching them, believing them to be 'caught' rather than 'taught' (Huntley and Donovan, 2010). Nevertheless, our four principles for cultivating habits of mind are grounded in well-established pedagogical research and practice (Campbell, 2006).

4.2 Principle 1: Developing understanding of the habit

The automaticity of habits often makes it difficult for students to see clearly what the skill involves, how to break it down into its component parts, or even to name it when they actually use it or notice it in others. It is important to explicitly define and explain the HoM so that understanding is developed on a practical as well as a theoretical level (Huntly and Donovan, 2010). Teachers frequently begin this process by talking with their students about their own personal experiences of using the skill, or provide examples of famous figures who have exhibited it. One of our FE lecturers wanted to increase his engineering students' persistence in mathematics, so in each lesson he introduced the students to biographies of engineers and scientists such as Dyson who had persisted with problems until they solved them. He observed that his students stayed on task much longer in lessons and became less reliant on him as the primary source of help when they got stuck. Some teachers use self-report questionnaires to help students gauge their own skill levels prior to discussing with them how they might enhance the skill, for example, Angela Duckworth's GRIT questionnaire (Duckworth Lab, 2015) is a popular choice for those wanting to develop the habit of persistence. We developed an Engineering Habits of Mind self-report survey which we have asked our teachers to pilot in their classroom interventions.

4.3 Principle 2: Create the climate for the habit to flourish

It is essential to create a climate that encourages and reinforces the habit for it to flourish within the learner. This climate may be created by ensuring that the habit is noticed and rewarded, by providing opportunities for repetition, by not seeing lack of success at the first attempt as failure but an opportunity to learn through 'having another go', and by supporting students in self-monitoring the extent to which they are using the habit. Positive reinforcement is an important element in habit formation, since learners need to experience the rewards and satisfaction associated with the successful execution of the task. Making verbal statements praising the skill exhibited rather than the individual is an effective method

of reward that serves two purposes; its praises the effort necessary for habit change and it also provides a further opportunity to make explicit what the desired behaviour entails. For example, instead of saying ‘well done Gina, you have made a good start’ a teacher might say ‘Gina, you're doing a great job of collecting all the material you need before you begin working," thus reinforcing the self-regulatory habit of managing resources.

Kel Fidler describes how a negative attitude to engineering can be produced when students are not given time to reflect on their mistakes nor a chance to repeat a task in order to get it right (Fidler, 2015). The opposite effect was noticed by one of our secondary teachers who wanted to increase his students’ ability for ‘problem finding’ in design & technology. He allowed the students to select their own topic for investigation, rather than allocating them himself, and allocated time for finding problems rather than telling students what they were. He noted that students identified interesting problems, spent more time on evaluating their designs and were able to propose better solutions after this review.

The need for expertise in self- monitoring is another important feature in the early stages of habit formation and ensures that learners become aware of occasions when they are or are not acting habitually. Encouraging learners to make an ‘implementation decision’ about when they are going to use the skill in response to a specific situation, ‘when X arises, I will do Y’ or, ‘when I finish dinner I will eat a piece of fruit’ establishes a connection between the desired habit and an existing routine (Stawarz et al. 2015). This use of imagining what you might do in certain situations has been shown to increase the likelihood of the intention being translated into action and the habit developing in the future as the behaviour becomes automatic (Gollwitzer et al. 2010).

4.4 Principle 3: Create the context and choose teaching methods which facilitate the practice and transfer of the habit

Although many changes to traditional engineering education practices have been taking place, it is recognised that more could be done (Borrego and Henderson, 2014). In our project we have been exploring the value of ‘signature pedagogies’, first developed by Shulman (2005) to describe discipline-specific teaching that recognizes the specific nature of knowledge in the discipline and the characteristics, including attitudes and attributes, of what it means to be a professional in that area. One example of a potential signature pedagogy for cultivating EHoM is the use of the engineering design cycle to highlight an holistic approach to problem solving. One of our primary teachers has used a simplified version of the design cycle to enable children to plan and complete their engineering projects which integrate outcomes in mathematics, science and technology. The children already proudly display their results on their school website.

Habits can also be cultivated or changed more readily through social support and the people we associate with via social networks can have a huge influence on our habit change (Christakis and Fowler, 2010). So the use of peer learning and collaborative learning in engineering programmes to develop personal and professional skills (Duffy and Bowe, 2010; Hermon and McCartan, 2010) is a positive development for the cultivation of EHoM.

As Perkins and Salomon (2012, p.248) observe ‘*Schools are supposed to be stopovers in life, not ends in themselves*’, since learning that takes place in school should prepare students for family, civic and professional life. Therefore pedagogies that support transfer of learning are important. Perkins and Salomon (1988) earlier suggested that some of the conditions that promote the development of learning transfer include:

- the provision of clear models, explanations and mental models at the point of first learning a new skill;
- specifically encouraging learners to consider how they might use what they are learning in other contexts at the point when they first learn something;
- extensive practice in different contexts;
- making as many connections as possible to the learner's existing knowledge.

These factors encourage learners to make the necessary connections between the prior learning situation and the new one and to understand the relationship between them. They also encourage learners to detect the possibility of a connection between prior learning and the new situation when they meet it. However, when the need arises to transfer learned habitual behaviour it is more difficult to ensure that learners elect to use a previously learned habit in a new situation, as competing counterforces come into play.

4.5 Principle 4: Build learner engagement and commitment to the habit

Having ensured that learners understand the habit and the contexts in which it can be used, having encouraged a climate in which it can flourish through reward and repetition, and having chosen teaching methods that facilitate its practice and transfer, the teacher can finally focus on building learner commitment to the habit by helping students own it and take personal responsibility for developing it. It has long been recognised that repeated exposure to something can make it seem more attractive to us; this is known as the 'mere exposure effect' first identified by Zajonc (1968), however, when the effective cultivation of the habit requires cognitive effort, self-regulation and active engagement by the learner, more purposeful strategies from the teacher are required. In building learner engagement, the teacher is seeking to encourage the student to '*join forces with the provider of the learning environment (i.e. the teacher) to create for themselves a motivationally supportive learning environment*' (Reeve, 2013, p.580). Thus the teacher should be utilising strategies that enable students to develop autonomy and self-efficacy. These might include, for example, the use of e-portfolios in which students can select, upload and display their best work (Simatele, 2015) or apps with which they interact to track and report on their skill development (Stawarz et al., 2015).

5. IMPLICATIONS FOR THE PRACTICE OF ENGINEERING EDUCATORS

5.1 Changing teacher beliefs to adopt new teaching habits

As we have seen already, habit formation is a slow process and it can be hard for teachers to change their teaching behaviours once habits have formed. They find it difficult to fully understand how to move from didactic to facilitative approaches (Courcier, 2007) and actually need considerable help in learning how to become more supportive towards students in fostering their autonomy (Su and Reeve, 2011). Even when lecturers believe they are engaged in student-centred activities in seminars, as in the engineering management class described by Hardman (2016), detailed video analysis of their interaction with students reveals that the sessions are largely lecturer-led with an emphasis on knowledge transmission. Furthermore, even when lecturers know that employers are asking for engineering graduates to have better employability skills, they seem unable to realise how these can be incorporated into their teaching and focus instead on adding new content, such as alternative energy sources (Naher et al., 2010). Another factor that may inhibit teachers actively cultivating habits of mind is the belief that it will interfere with the teaching of the subject, or that it is something extra that has to be fitted into an already crowded curriculum. With so much

emphasis now on high-stakes accountability in education, this fear is not surprising. However, as Hattie (2009) has demonstrated, enhancing students' thinking skills is one of the most effective ways of enhancing their overall academic achievement.

5.2 Making teaching and learning processes visible

Hattie (2009) has also suggested that it is important to make teaching and learning processes visible. However, teachers can find it difficult to put themselves in the learner's position once they have become an expert in their discipline and its disciplinary habits of mind and may miss out references to important steps in thinking (Wineberg, 2003). This is why CPD is important to help them develop the understanding and skills to adapt their teaching to cultivate HoM. Fortunately, there is now extensive research into teachers' professional development that identifies the most important components necessary to encourage teachers to shift from the mindset of teacher to one of learner about their teaching practice and to embed new approaches. Professional development is most effective when teachers engage in classroom-based inquiry and focus on an aspect of their students' learning that they would like to change, when collaboration between teachers within the school is encouraged and when they are involved in professional learning communities to share and disseminate practice (Stoll et al., 2012). All these feature which have been incorporated into our project, as discussed in section 2.

6. CONCLUSIONS

This is a qualitative study involving a small number of schools and colleges, so there are limitations to the conclusions we can draw from it. However, we identified engineering habits of mind to prompt a re-imagining of the 'shortage of engineers' challenge, suggesting that if we knew more about the thinking strategies used by engineers when tackling engineering problems, we could cultivate these in young people and possibly encourage more of them to consider engineering as a career. Since habits of mind are strongly connected to employability in the longer term (Lucas and Hanson, 2016), it would appear be worth considering how they might contribute to a planned employability strategy and to identify pedagogies that cultivate them effectively in the classroom. This is best done in parallel with subject content but may require teachers to adapt their teaching strategies to align with the four principles described in this paper.

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